Gait Posture. Author manuscript; available in PMC 2010 February 1.

Published in final edited form as:

Gait Posture. 2009 February ; 29(2): 242–248. doi:10.1016/j.gaitpost.2008.08.012.

Critical Features of Training That Facilitate Adaptive Generalization of Over Ground Locomotion

Ajitkumar P. Mulavara[(a)], **Helen S. Cohen**[(b)], and **Jacob J. Bloomberg**[(c)]

a) *Universities Space Research Association*

b) *Bobby R. Alford Department of Otolaryngology – Head and Neck Surgery, Baylor College of Medicine*

c) *Neuroscience Laboratories, NASA/Johnson Space Center*

Abstract

When subjects learn motor tasks under novel visuomotor conditions variations in sensory input during training facilitate adaptive generalization. We tested the hypotheses that training with multiple sensory input variations is more effective than a single or no variation and that training must include critical features of the criterion task. Normal adults were pre- and post-tested on an obstacle avoidance task while wearing visual distortion lenses after treadmill walking (Experiment 1), or balance training (Experiment 2). Subjects were randomized to training groups in which they wore either: 1) three different visual distortion lenses, 2) a single pair of visual distortion lenses, or 3) sham lenses. Post-tests were done while wearing novel lenses. In Experiment 1 subjects who trained with multiple lenses adapted better than single or sham lens groups. The single lens training group with magnifying lenses adapted better than the other single lens groups. In Experiment 2, training for dynamic balance, alone, did not increase training efficacy. Thus, training for an obstacle avoidance task in a novel visual environment required a critical feature of the criterion task: locomotion. Constant practice with a single lens was successful only if the best lens was selected, but the best lens could not be known ahead of time. Therefore variable practice with multiple lenses on a task that included a critical feature of the criterion task was the best training strategy to enhance adaptive generalization.

Keywords

balance therapy; motor learning; plasticity; locomotion; rehabilitation

Introduction

People are often faced with new performance challenges, ranging in complexity from writing with a new pen to driving a novel car. To perform successfully on the first trial of a novel motor task, people must be able to generalize from previously learned motor skills, developing classes of responses to classes of stimuli. Therefore, even though a specific performance challenge is unique, the performer can generalize from pre-existing schemata (1). This ability to transfer training from a learned class of motor skills to a novel movement challenge is adaptive generalization.

Address correspondence to: Helen Cohen, EdD, OTR, Department of Otolaryngology, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030 or e-mail (hcohen@bcm.tmc.edu).

Training for specific motor tasks with variations in sensory input facilitates adaptive generalization to novel sensorimotor conditions (2-7). Training under invariant conditions is less likely to lead to adaptive generalization than training under conditions that include variability (8-12). Previous experiments supporting this idea have not tested transfer of training in novel sensorimotor environments. Therefore, those results may have limited application to training of individuals who work under unusual environmental conditions or who suffer permanent sensory impairments.

Exposure to multiple changes in visual/motor relationships during training facilitates learning a motor task that requires an adaptive response to a novel visual input. For example when subjects learned either throwing or obstacle avoidance tasks and then performed those tasks while wearing lenses that distorted the visual image in a way to which they had not been trained, subjects who were exposed to several different types of visual distortion lenses during training performed significantly better than subjects trained with sham lenses (3,5). Thus, they were better able to develop adaptive generalization. Conversely, when stroke patients were trained on a balance training paradigm with and without vision using constant practice, rather than variable practice, the group trained without vision performed better on select balance tasks (13). Therefore, if the performer will train with a single sensory variation the trainer must select the single condition that best approximates the subsequent performance requirements.

Adaptive generalization occurs in response to novel visual inputs from different types of lenses (6,14,15), during obstacle avoidance training under different treadmill walking conditions (16), from walking to reaching (17), and for reaching movements under varying force fields (18). Thus performers who practice solving classes of motor problems can improve their adaptive abilities. Performers who train for adaptive generalization under varying sensory conditions or response patterns may learn to generalize better than performers trained with only one solution or one response pattern (19). No previous studies have investigated the role of the degree of variations in critical features of gross motor tasks during locomotor training in preserving adaptive generalization. The current study was planned to determine how changes in the critical features of the motor task during training affects performance on an obstacle avoidance task (the criterion task). This study included two experiments that provided similar variations in visual input conditions while changing the motor task during training from treadmill walking to dynamic standing balance alone. Both experiments tested performance using novel visual input conditions not experienced during training on the criterion, obstacle avoidance, task.

Methods

General Materials and Methods

All subjects were normal adults recruited from among the staff and students of the institutions at the Texas Medical Center, with no history of otologic, neurologic, or orthopedic disorder. Subjects who wore corrective lenses used them during training and testing and had at least 20/40 vision with their corrective lenses. These experiments were approved by the Institutional Review Board for Human Subject Research for Baylor College of Medicine and Affiliated Hospitals. Subjects gave informed consent prior to participation.

In both experiments, subjects were randomized to training groups in which they wore either: 1) three different visual distortion lenses, 2) a single pair of visual distortion lenses, or 3) sham (clear) lenses. The lenses were all set in lightweight, black, plastic, safety goggles that accommodated eyeglasses but eliminated 25° of peripheral vision to each side. In both experiments, each group received a different type of visuomotor transformation during training by wearing the lenses. The lenses were as follows: 1) clear plastic with no special optical

properties (sham), 2) X 2.0 magnifying lenses, 3) X 0.5 minifying lenses, 4) up/down reversing lenses.

In both experiments subjects were pre-, post-, and retention-tested with the Functional Mobility Test (FMT), using an obstacle course in a 5.5 X 6.7 m room. The base of the course was 10 cm thick, medium density foam (5 lb/ft^3, Sunmate foam with skin-soft coating, Dynamic Systems, Inc., Leicester, NC). The compliant foam changes continually as the individual stands on it, making the support surface unreliable. The foam was used to make proprioceptive information unreliable during ambulation. It had an added benefit for safety: if anyone had fallen it would have provided a soft landing. The use of an obstacle course has been validated for clinical testing in evaluation of elderly people with balance impairments (20).

Obstacles included two pleated fabric curtains suspended from the ceiling, pairs of Styrofoam blocks (96.5 cm (height) X 40.6 cm (width) X 10.2 cm (thickness) per block), 8 pairs of colorful, inflated, polyethylene, sand-weighted children's punching bags, (also called “bop” bags), 0.9 to 1.4 m high and 0.3 m diameter, four 15-cm spots on one side of the course that gave auditory cues (buzzers) when subjects walked on them, and a low Styrofoam block (193 cm X 20.3 cm X 10.2 cm) placed on either end of the foam section in which the buzzers were located. Instructions were to walk through the course as rapidly as possibly without touching any obstacles but to step on the buzzers. The dependent measures were the time (sec) to traverse the course timed with a stopwatch (time), and the number of obstacle errors, i.e. the number of obstacles touched plus the number of buzzers missed (obstacles). This test was slightly modified from one that has been described elsewhere (21). See Figure 1.

For both experiments two pre-test trials were done without lenses. (A trial was one round of walking through the obstacle course.) Subjects were tested on two post-test trials, 2 to 4 days after the last training session, and two retention trials, two weeks after the post-tests. During the post-test and retention trials subjects wore 20° shift right lenses that they had never worn before, to expose them to a novel visuomotor transformation. Technicians who were blinded to subjects' group assignments administered all tests. Inter-rater reliability, using 10 subjects who did not otherwise participate in the study, was: time, $r = 0.98$, $p < 0.0001$; number of obstacles touched, $r = 0.9$, $p < 0.001$.

Experiment 1: Treadmill Training

In daily life, people must adapt their motor skills to novel situations for which they have not trained. Therefore, this study trained subjects on a locomotor task different from the test task. After pre-tests subjects were trained by walking on a treadmill. This training task differed from the test task in 3 important respects. 1) The surface of the obstacle course was compliant but the surface of the treadmill was noncompliant. 2) When traversing the obstacle course the subject followed a complex spatial trajectory, including turns, but the treadmill training involved no such trajectory. 3) Visual cues during the FMT were salient to the task. During locomotor treadmill training, visual stimuli were not matched to walking velocity. The use of a treadmill also had a practical basis; many training environments have space for a treadmill and safety harness but not for a walking track with a safety harness on a moving track. This experiment tested the idea that treadmill training would carry over to over ground locomotion.

Eighty subjects -- 54 females, 26 males, mean age 31.4 yrs (S.D. 10.1) -- were randomly assigned to one of 5 training groups: sham lenses (n = 20), multiple lenses with the magnifying, minifying, and up/down lenses (n = 20), single lenses with magnifying lenses (n = 20), single lenses with minifying lenses (n = 10) and single lenses with up/down reversing lenses (n = 10). After pre-tests subjects had five 20-min training sessions, given over one week, on the treadmill (Quinton Model Q55) at 3 km/hr, and simultaneously watched videotapes on a screen at eye level 2 m in front of them. The videotapes were popular films chosen by subjects. While

watching videotapes they wore lenses for three 6-minute intervals with two 1-minute inter-interval breaks. During the break subjects in the multiple lens group switched lenses. Subjects in the other groups stopped walking and lifted up their lenses.

Experiment 2: Wobble board training

Experiment 2 was done to determine if adaptive generalization could still be elicited when the locomotor aspect of training was eliminated and balance training was constrained to standing on a wobble board. This question is practical. Many clinicians who provide balance therapy do standing balance training to improve walking balance skill, which may not be the best strategy. Instead of treadmill walking subjects stood on a wobble board, which challenged their balance on a noncompliant surface but without locomotion.

Sixty-three subjects -- 34 females, 29 males, mean age 27.4 yrs (S.D. 6.9) – had not participated in Experiment 1. They were randomized to 3 groups with 21 subjects per group: sham, multiple lenses with the magnifying, minifying and up/down lenses, and single lens practice with magnifying lenses. The experiment used a plastic wobble board (Flaghouse Balance Disk, 9 cm high, with a rounded base such that it tapers gradually from 39.5 cm diameter on top to 3 cm diameter at the base), which has multiple degrees of freedom. The lack of a stable support point challenged the subject's dynamic standing balance during training. The subject stood on the board with both feet, wearing a safety harness in case of falls, but the harness did not provide support. The training schedule, lenses, videotapes and FMT from Experiment 1 were retained.

Statistical analyses

Learning effect between trials—Paired t-tests were performed across the two trials for time and obstacle errors (obstacles) during each of the three test sessions (pre-test, post-test, and retention test) to determine if the first and second trials performed at each test session differed significantly. All statistical tests were performed with the SPPS statistical software v11.0 and significance level was set at alpha = 0.05.

Effects of experimental manipulations—A univariate ANOVA was performed for the pretest obstacles and time to determine if these variables differed significantly for the two between-subject factors, Experiment and Lens Group (Experiment had two levels – treadmill and wobble board; Lens Group had three levels –sham, single lens group with magnifying lenses, variable lenses). Significant differences at the pretest would have warranted use of the pretest value as a covariate in further analyses.

Repeated measures analyses of variance (RMANOVA) were used to test the time and obstacle data (one within subject factor – Session, three levels: pretest, post-test and retention; two across subject factors: Experiment and Lens Group: Experiment had two levels – treadmill and wobble board; Lens Group had three levels – sham, single lens group with magnifying lenses, variable lenses). Tables 1 and 2 give descriptive statistics for Experiments 1 and 2, respectively.

Effect of single lens training over multiple lens training—To determine if training using different single lenses was as beneficial as training with variable lenses repeated measures ANOVAs for time and obstacles were also performed separately for the treadmill training experiment (Within subject factor – Session, three levels: pretest, post-test and retention; Between subject factor – Lens Groups: five levels – sham, single lens group magnifying, single lens group minifying, single lens group up/down, and variable lens group).

Results

Obstacle Errors

Learning effect between trials—For obstacles, with lens groups and experiments collapsed, pre-test Trials 1 and 2 did not differ significantly (t=0.7, p=0.5). At the post- and retention tests, however, slightly but significantly fewer obstacles were touched at Trial 2 (post-test: t=8.1, p<0.0001; retention test: t=7.8, p<0.0001). When the data were broken down by experiments, for Experiment 1 no difference was found between trials at the pretest (t=0.3, p=0.8). At the post- and retention tests, though, significantly fewer obstacles were touched at Trial 2 (post-test: t = 4.4, p<0.0001; retention test, t = 6.2, p< 0.0001). In Experiment 2, t-test results showed that the pre-test Trials 1 and 2 did not differ significantly (t=0.9, p<0.3). At the post- and retention tests, however, significantly fewer obstacles were touched on Trial 2 (Post-test: t = 6.9, p< 0.0001; Retention test: t = 4.7, p< 0.0001). These data suggested a learning effect over trials for obstacles. Therefore, subsequent analyses for obstacles used only Trial 1.

Effects of experimental manipulations—A univariate ANOVA on the pretest obstacles score revealed a significant main effect of the between subject factor Experiment (F(1,117) = 8.527; p = 0.004). No significant effects were found for the between subject factor, Lens Group (p>0.05), and no interactions between factors were significant (p>0.05). Hence the variable, obstacles, in the pretest was used as a covariate in the RMANOVA. See Figure 2.

The RMANOVAs on obstacles with the pretest as a covariate revealed significant main effects of Session[$F_{(1,115)}$ = 12.142, p =0.001] and Experiment[$F_{(1,115)}$ = 4.041, p =0.047]. No significant effects were found for the between subject factor, Lens Group (p>0.05), and no interactions between factors were significant (p>0.05). Therefore, although subjects had more obstacle errors on the post test than the retention test, across all three lens groups within each experiment, subjects performing the wobble board training had significantly less obstacle errors than the treadmill training group. See Figure 2.

Effect of single lens training over multiple lens training—The RMANOVA for obstacles using the 5 different lens groups in Experiment 1, treadmill training, revealed a significant main effect of Session [$F_{(8,150)}$ = 100.209, p <0.0001]. No significant effect was found for the between subject factor, Lens Group (p>0.05), and no interactions between factors were significant (p>0.05). Therefore, across all five groups undergoing treadmill training, subjects made more obstacle errors on the post- and retention tests than the pretest. On the retention test subjects made significantly fewer obstacle errors than on the post-test.

Time Around the course

Learning effect between trials—For time, with lens groups and experiments collapsed, t-tests showed that Trials 1 and 2 differed significantly at pre-test, post-test and retention test (pre-tests: t=2.4, p<0.02; post-tests: t=6.6, p<0001, retention tests: t=4.2, p<0.0001), indicating that Trial 2 was faster. When the data were broken down by experiments, for Experiment 1 pre-test Trials 1 and 2 did not differ significantly (t=1.1, p=0.3) but times were significantly reduced at Trial 2 at the post-test (t = 4.5, p< 0.0001) and retention test (t = 2.7, p<0.01). For Experiment 2 times were always significantly faster on Trial 2 (Pre-test: t=2.9, p=0.006; Post-test t = 4.8, p<0.0001; Retention test: t=3.2, p=0.002). These data suggested a learning effect over trials for time. Therefore, subsequent analyses for time used only Trial 1.

Effects of experimental manipulations—A univariate ANOVA on the time for the pretest revealed no significant main effects for the between subject factors Experiment and Lens Group or for any of the between factor interactions (p >0.05). Hence, the time in the pretest was not used as a covariate in the RMANOVA.

The RMANOVA revealed a significant main effect of the within subject factor, Session [$F_{(2,234)} = 108.512$, $p < 0.0001$], and a significant interaction for Experiment * Lens Group * Session[$F_{(4,234)} = 2.857$, $p < 0.024$]. No other interactions were significant. Therefore, across all three lens groups undergoing treadmill or wobble board training, subjects took more time on the post- and retention tests than the pretest. On the retention test subjects took significantly less time than on the post-test. See Figure 3.

Because of the significant interaction among the three factors: Experiment, Lens Group and Session, a RMANOVA was then performed separately for each of these factors: Experiment and Lens Group for each Session level; Session and Experiment for each Lens Group level; Session and Lens Group for each Experiment level. The RMANOVA for each of the Session levels revealed no significant main effects or interactions between them ($p>0.05$). The RMANOVA for each of the Lens Groups revealed a significant effect for the factor, Session, for each of the Lens Groups ($p<0.001$). The factor, Experiment, and the interaction between the factors was not significant ($p>0.05$) for each of the Lens Group levels. However, the RMANOVA for Session and Lens Group for each Experiment level revealed the following results: For Experiment 1, treadmill training, the RMANOVA (Within subject factor – Session, three levels: pretest, post-test and retention; vs. Across subject factor – Lens Groups: three levels – Sham, single lens group – magnifying and variable lens group) revealed a significant main effect of Session[$F_{(2,114)} = 82.171$, $p < 0.0001$] and a significant interaction for Lens Group * Session [$F_{(4,114)} = 3.316$, $p < 0.013$]. No significant effects were found for the between subject factors of Lens Group ($p>0.05$). For Experiment 2, wobble board training, the RMANOVA revealed only a significant main effect of Session [$F_{(2,120)} = 46.192$, $p < 0.0001$]. No significant effects were found for the between subject factors of Lens Group ($p>0.05$) and no interactions between factors were significant ($p>0.05$). Therefore, across all three groups undergoing Treadmill and Wobble board training, subjects took more time on the post- and retention tests than the pretest; at the retention test subjects took significantly less time than at the post-test. See Figure 3.

Because of the Lens Group * Session interaction, for Experiment 1: treadmill training, a univariate ANOVA across the three lens groups (Sham lens, Single lens magnifying and Variable lens) was performed on the percent differences of time for pretest to posttest [$(\text{time}_{\text{posttest}} - \text{time}_{\text{pretest}})*100/\text{time}_{\text{pretest}}$] and pretest to retention [$(\text{time}_{\text{retention}} - \text{time}_{\text{pretest}})*100/\text{time}_{\text{pretest}}$] measurements. The ANOVA revealed a significant difference among the three lens groups [pretest to posttest: $F_{(2,57)} = 5.431$, $p < 0.007$; pretest to retention: $F_{(2,57)} = 4.138$, $p < 0.03$]. Post-hoc Fishers's Least Significant Difference Tests (LSD) on the percent difference between the pretest to posttest and pretest to retention time showed significant differences between: 1) the sham and single lens magnifying groups (pretest to posttest : $p<0.02$; pretest to retention: $p<0.01$) and 2) the sham and variable lens groups (pretest to posttest : $p<0.004$; pretest to retention: $p<0.04$). The single lens magnifying and variable lens groups, however, did not differ significantly for both pretest to posttest and pretest to retention time ($p>0.05$). See Figure 4. Therefore, on both the post- and retention tests subjects in the sham group took significantly more time to complete the course than subjects in the single lens magnifying and variable lens groups. The single lens magnifying and variable lens groups did not differ significantly.

Effect of single lens training over multiple lens training—The RMANOVA for time using the 5 different lens groups in Experiment 1, treadmill training, revealed a significant main effect of Session [$F_{(2,150)} = 110.668$, $p < 0.0001$] and a significant interaction for Lens Group * Session [$F_{(8,150)} = 2.231$, $p < 0.028$]. Therefore, across all five lens groups undergoing treadmill training, subjects took more time on the post- and retention tests than the pretest. On the retention test subjects took significantly less time than on the post-test.

Because of the Lens Group * Session interaction for time, a univariate ANOVA across lens groups was performed on the percent differences of time for pretest to posttest [(time $_{pretest}$ – time $_{posttest}$)*100/time $_{pretest}$] and pretest to retention [(time $_{pretest}$ – time $_{retention}$)*100/ time $_{pretest}$] measurements. The results revealed a significant difference among the five lens groups for the percent difference only for pretest to posttest ($F_{(4,75)} = 3.697$, $p < 0.009$) and not for pretest to retention (p>0.05). Post-hoc LSD on the percent difference across lens groups for pretest to post-test revealed significant differences between: 1) the variable and sham lens groups (p<0.006); 2) the variable and single lens minifying groups (p<0.04); 3) the variable and single lens up/down groups (p<0.02); 4) the sham and single lens magnifying groups (p<0.02); and 5) the single lens magnifying and single lens up/down groups (p<0.03). The sham lens group did not differ significantly from either the single lens minifying or single lens up/down groups (p > 0.05). The single lens magnifying group did not differ from the single lens minifying or variable lens groups (p > 0.05). See Figure 4. Therefore, these findings suggest that among groups using the single lenses only the magnifying lens group had equivalent performance compared to the variable lens group during the obstacle avoidance task tested using the novel, 20° shift right lenses and further that both these lens groups took less time to traverse the course than the sham lens group.

Discussion

This study tested a training strategy for adapting to a novel visual input and examined how changes in certain features of the training task affected performance on the criterion test. These features included the compliance of the support surface, the act of locomotion, translation through space during locomotion, and the type of visual/motor relationship.

Critical task features

Training was most effective for development of adaptive generalization when training included a critical feature of the criterion task, locomotion. Treadmill locomotion, which does not allow linear translation, visual flow or turning, was still effective. When training eliminated locomotion, however, neither single nor multiple variations in lenses facilitated adaptation. These data suggest that performance and training conditions need not be identical, but the training paradigm must include critical features of motor performance in the criterion task. So, if the performer must walk around in the environment after training or therapy then training with only standing balance is not an adequate strategy because the task requirements are too different.

Previous work supports these ideas. Adaptation to a novel manipulative task can occur after previously learning another manipulative task but the conflict or independence of the two tasks influences transfer of training; when task requirements conflict learning a new task is more difficult (2). Transfer of training occurs when training includes critical features of the criterion task (14). Therefore, if the sole training task includes dynamic stability only during standing, such as on a therapist's rocker board, then training will not transfer to gait.

The underlying mechanisms controlling balance and mobility performance requires both static and dynamic balance (26). Indeed, our results indicate that training for standing balance using a wobble board may provide an advantage over treadmill walking in improving obstacle avoidance strategies for a novel task. Even though some static balance tests, e.g. the Berg Balance Scale, may be effective predictors of falls (25), however, other static balance tests, e.g., the Tandem Stance Tests, are less correlated with mobility performance. When stability during standing and walking were compared, responses to perturbations during standing were on a much shorter time scale than responses during walking, suggesting that different mechanisms control standing and walking (27). Our results confirm and extend this finding,

since training for standing balance is not sufficient to improve functional locomotion. Treadmill training, although not optimal, is still more effective than standing balance training.

Visuomotor changes

We examined the influence of the type of visual/motor relationship more closely in Experiment 1 with several single lens groups compared with the multiple and sham lenses. The data showing the equivalency of training between the single lens magnifying and multiple lens groups. Subjects in the single lens minifying or single lens up/down lens groups, however, showed significantly increased time to traverse the course compared to the multiple lens groups. This finding might have several explanations. Perhaps the transformation required for magnifying lenses is a greater sensorimotor challenge during training compared with the other single lenses. This concept is supported by the finding that increasing the vestibulo-ocular reflex gain with magnifying lenses is more challenging for the vestibular system than reducing the gain an equivalent amount with minifying lenses (22,23). These ideas are also supported by our previous finding with a different obstacle course that when minifying lenses were the novel lenses used during the post-test, single lens practice with right shift lenses was not efficacious but single lens practice with magnifying lenses was better than sham (3). Up/down reversing lenses are disorienting and difficult for most people to use. A successful strategy for wearing up/down reversing lenses may not transfer to other conditions. In his seminal paper Stratton described the difficulty of using reversing lenses (24). Thus, selecting a single type of practice or exposure may not be the best strategy for facilitating adaptive generalization, if the single most effective input among all the possible options is not already known.

Support for Variable Practice

Training programs should incorporate as much sensory variation as possible, including variations in visual flow coupled with changes in speed and alterations of the treadmill support surface (28-30). Our results support and extend previous studies showing that motor training with multiple visual transformations improves the ability to adapt to a novel visual environment (2,3,5,6,31). Since most people will eventually experience performance conditions different from training, to facilitate performance under novel conditions training should include variability.

Acknowledgements

Supported by NIH grant DC04167 and the National Space Biomedical Research Institute through NASA NCC 9-58. We thank the staff of the Center for Balance Disorders, Baylor College of Medicine, for technical assistance and Dr. Deborah Harm of NASA Johnson Space Center for assistance with statistical analysis.

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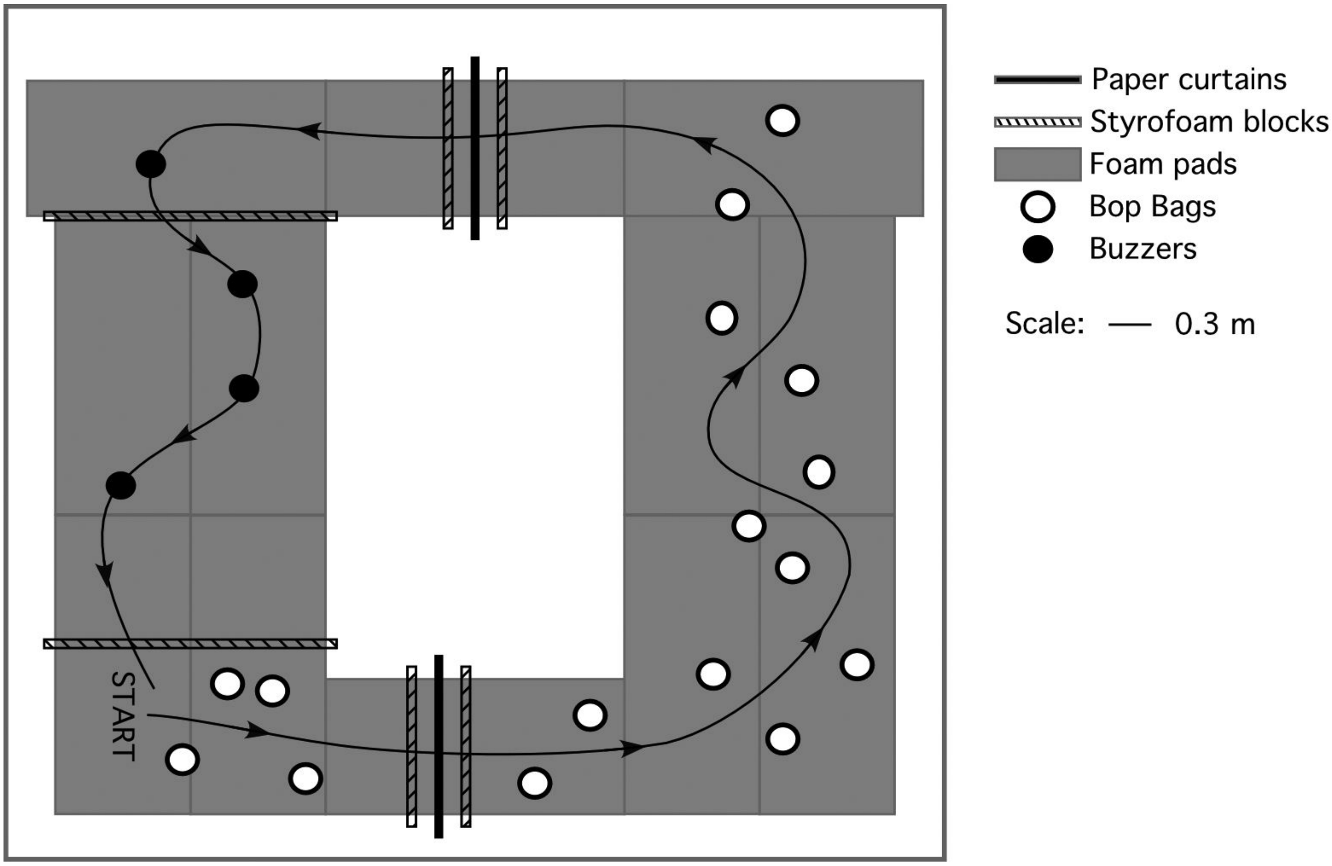

Figure 1.
Plan view of the FMT obstacle course. Modified from Moore et al (18). Used with kind permission of Springer Science and Business Media.

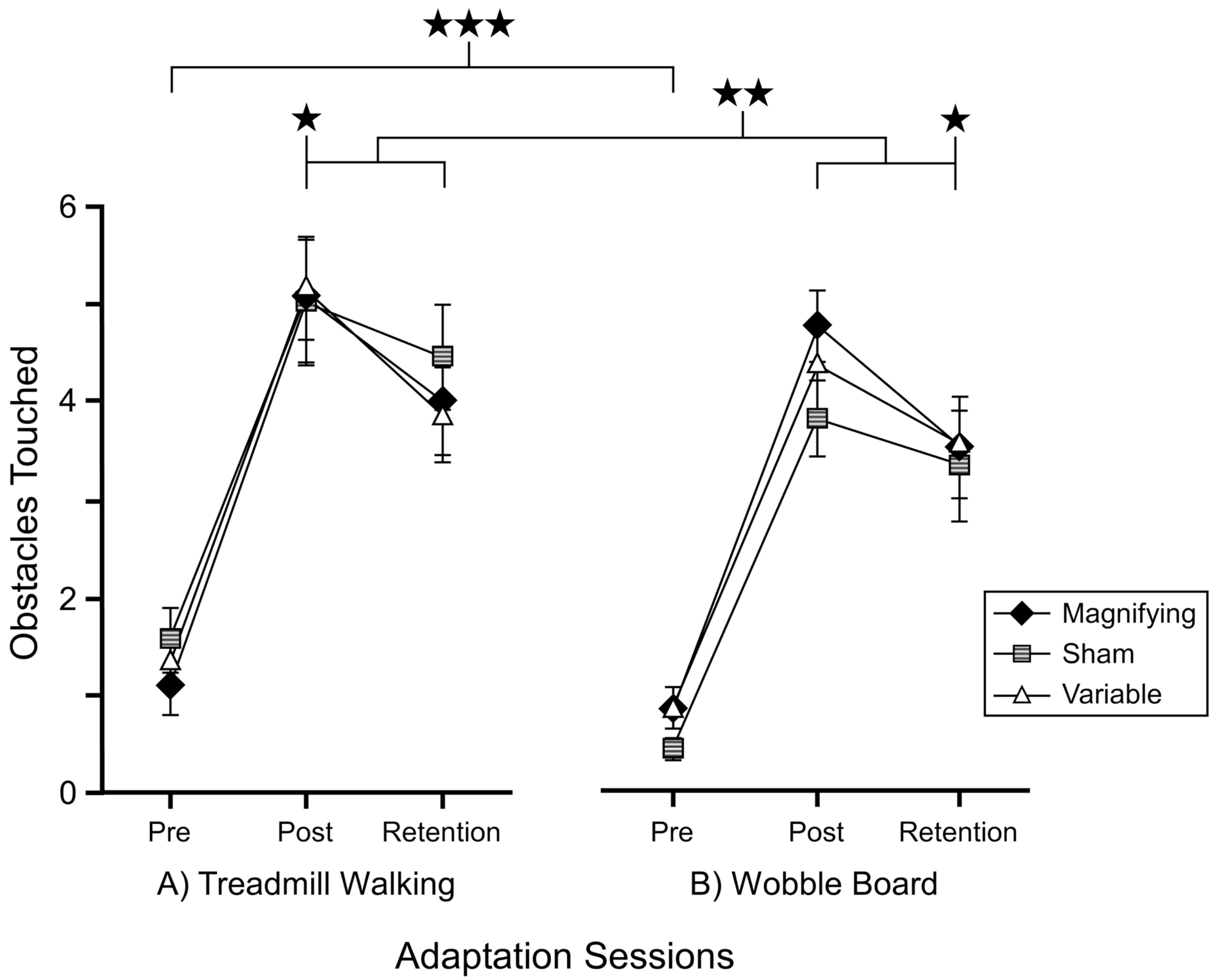

Figure 2.

Mean scores (± one standard error of the mean) by test dates and groups for obstacle errors by - Experiment 1: treadmill training; and Experiment 2: wobble board training. A univariate ANOVA on the obstacle errors for the pretest revealed a significant main effect for the factor Experiment (★★★) and hence was used a covariate for further analysis. A RMANOVAs on obstacles with the pretest as a covariate revealed significant main effects for Session (★, two levels: posttest and retention) and Experiment (★★, two levels: Treadmill and Wobble Board).

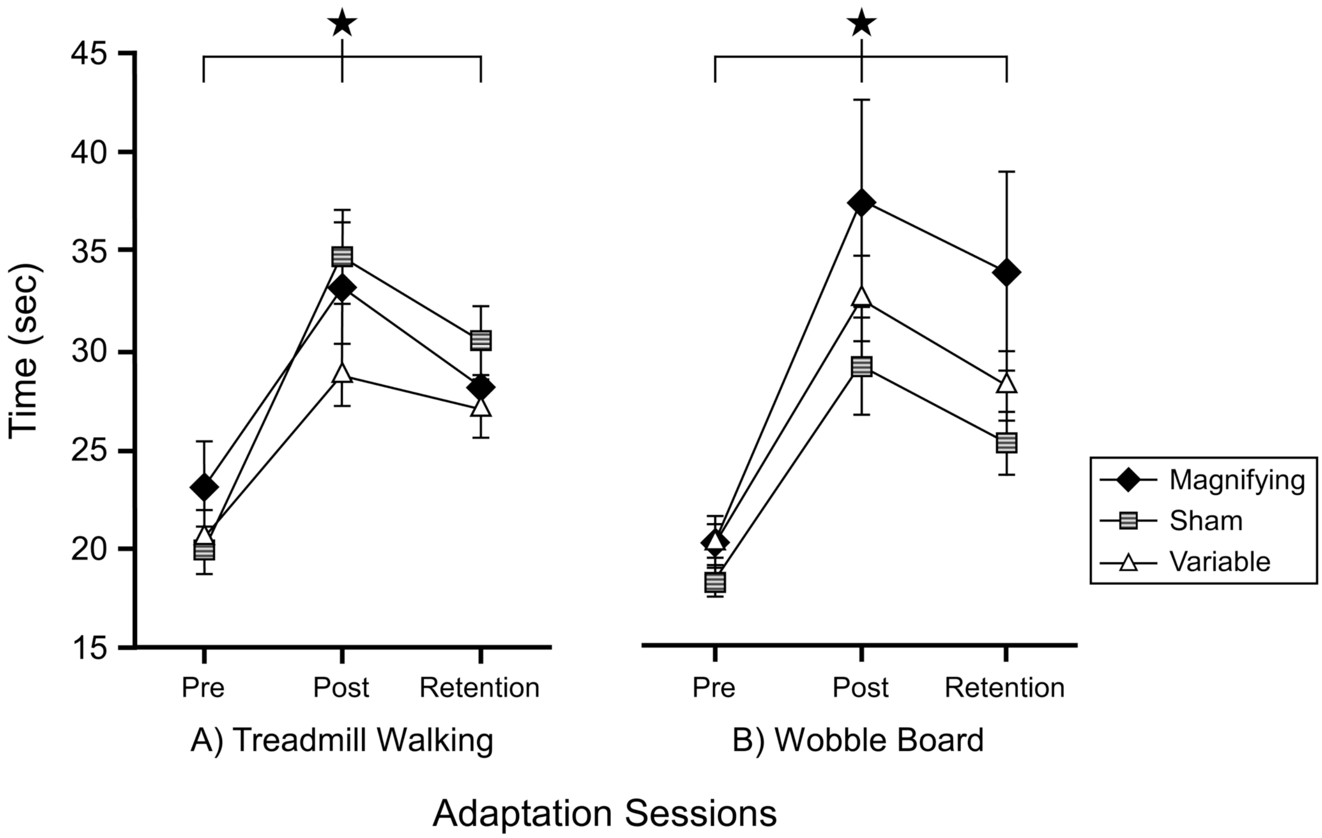

Figure 3.
Mean scores (± one standard error of the mean) by sessions and group for time by - A) Experiment 1: treadmill training; and B) Experiment 2: wobble board training. A RMANOVAs on time revealed a significant main effect for Session (★, three levels: pretest, posttest and retention) and a significant interaction between Sessions, Lens Groups and Experiment.

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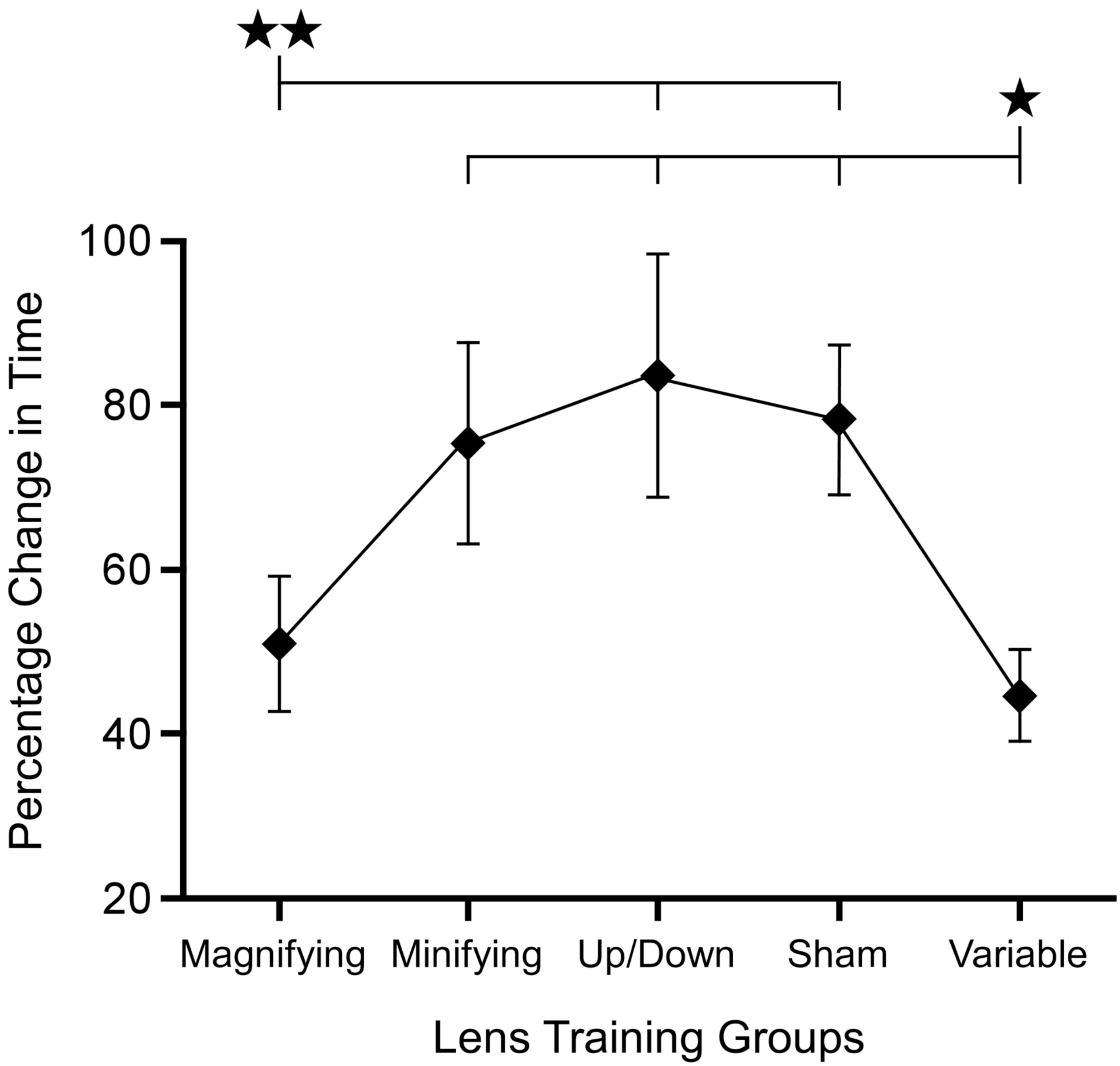

Figure 4.

Mean (± one standard error of the mean) percentage change in time by each of the five training groups of the post test (Session 5, 20° shift right lenses) in Experiment 1 - Treadmill walking. A univariate ANOVA across lens groups on the percent differences of time for pretest to posttest revealed: 1) the variable lens group is significantly different from the sham, the single lens minifying and the single lens up/down groups (★) and 2) the single lens magnifying is significantly different from the sham, and the single lens up/down groups (★★).

Table 1

Data from Experiment 1: Treadmill training.

A. FMT time. Values given are means (standard deviations)						
Training Group	**Time (sec)**					
	Pretest		**Posttest**		**Retention**	
	Trial 1	**Trial 2**	**Trial 1**	**Trial 2**	**Trial 1**	**Trial 2**
Sham	19.9 (5.4)	18.7 (6.0)	34.7 (10.5)	30.0 (8.8)	30.4 (8.4)	28.8 (9.3)
Single lens, Magnifying	23.0 (10.6)	21.5 (6.9)	33.2 (15.1)	31.7 (12.9)	28.1 (9.8)	27.7 (14.1)
Single lens, minifying	20.5 (2.1)	21.6 (8.1)	33.8 (8.3)	28.4 (8.5)	30.0 (10.0)	25.3 (7.4)
Single lens, up/down	20.2 (5.2)	17.3 (4.6)	37.0 (16.5)	32.2 (13.9)	31.3 (14.1)	28.5 (10.4)
Multiple lens	20.7 (5.5)	21.2 (7.0)	28.2 (6.8)	26.2 (6.6)	27.2 (6.8)	25.3 (6.8)
B. FMT obstacles touched. Values given are medians [ranges]						
Training Group	Obstacles					
	Pretest		Posttest		Retention	
	Trial 1	Trial 2	Trial 1		Trial 1	Trial 2
Sham	2 [0-5]	1 [0-6]	6 [3-12]	4 [0-10]	5 [1-12]	3 [0-9]
Single lens, Magnifying	1 [0-4]	1 [0-4]	6 [2-14]	4 [1-16]	4 [0-10]	3 [0-13]
Single lens, minifying	1 [0-6]	0.5 [0-6]	5.5 [2-16]	3.5 [1-15]	5 [1-12]	2.5 [1-12]
Single lens, up/down	1 [0-4]	1 [0-5]	6.5 [3-10]	5 [1-11]	6 [1-11]	4 [2-10]
Multiple lens	1 [0-4]	0.5 [0-3]	6 [1-11]	4 [0-13]	4 [0-10]	2.5 [0-8]

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Table 2

Data from Experiment 2: Wobble board training.

A. FMT time (sec). Values given are means (standard deviations)						
Training Group	**Time (sec)**					
	Pretest		**Posttest**		**Retention**	
	Trial 1	**Trial 2**	**Trial 1**	**Trial 2**	**Trial 1**	**Trial 2**
Sham	18.3 (3.6)	18.1 (5.9)	29.1 (11.2)	25.8 (7.9)	25.2 (7.2)	24.2 (8.7)
Single lens	20.3 (5.9)	18.6 (6.0)	37.2 (23.7)	30.1 (15.9)	33.8 (22.9)	29.1 (17.5)
Multiple lens	20.3 (3.9)	18.2 (3.8)	32.5 (9.6)	27.5 (9.6)	28.1 (8.2)	25.7 (9.6)
B. FMT obstacles touched. Values are medians [ranges].						
Training Group	Obstacles					
	Pretest		Posttest		Retention	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Sham	0 [0-4]	0 [0-3]	4 [1-7]	3 [0-6]	3 [0-11]	1 [0-13]
Single lens (magnifying)	1 [0-3]	1 [0-5]	6 [2-10]	3 [0-9]	4 [0-8]	2 [0-7]
Multiple lens	1 [0-4]	0 [0-5]	4 [1-15]	2 [0-11]	3 [1-11]	2 [0-10]